Reducing Chemical Inputs in Vegetable Production Systems Using Crop Diversification Strategies

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Authority of access

Declaration of originality

This thesis reports the original work of the author, except where due acknowledgement is given, and has not been submitted previously at this or any other University.

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Abstract

Vegetable cropping systems are becoming larger, more specialised and increasingly reliant on agro-chemicals to manage pests, diseases and weeds. These trends in vegetable production have resulted in increased efficiencies and allowed producers to maintain profitability in a marketplace with greater competition and declining gross margins. However, concern is growing among consumers about the impacts of chemicals on human health and the environment. This research program explores the benefits and costs of alternative vegetable production systems with increased plant species diversity and their potential to reduce chemical inputs.

The first trial conducted in this study focused on strip cropping with the view of adding additional layers of diversity in subsequent experiments. The trial used large plots with mixtures and monocultures of three vegetables: onions (*Allium cepa*), broccoli (*Brassica oleracea* var. italica) and potatoes (*Solanum* tuberosum). These vegetables were chosen to maximise diversity as they all have very different harvested products and do not share any major pests or diseases. This initial trial found that most vegetable diseases were too virulent to control with diversity alone and that onions were very poor competitors and hence not suited to mixed cropping systems. Furthermore, production benefits were found to occur at the zone of interaction, meaning that smaller plots with increased replication could be used in subsequent experiments. There were also trends indicating that the insect pest of broccoli *Plutella xylostella* was restricted by the mixed cropping system.

A cover crop of cereal rye (*Secale cereale*) was chosen as an additional layer of diversity in the second trial conducted in 04/05, due its ability to be easily killed and rolled to form a thick mat of plant material for suppressing weeds. Results from this experiment found that the numbers of *P. xylostella* and the aphid *Brevicoryne brassicae* in broccoli were significantly reduced by the cover crop but not by the broccoli/potato strip crop. Another pest of broccoli, *Pieris rapae*, was not affected by either treatment. The experiments also showed that there were no significant differences in yield or quality of both potatoes or

broccoli, in spite of the fact that broccoli grown in a cover crop matured one week later than broccoli grown in conventionally prepared soil (i.e. a bare soil background).

Experiments in 05/06 showed that reductions in the numbers of *P. xylostella* and *B. brassicae* in broccoli grown in the cover crop were primarily due to interference with host location and not predation or reduced host plant attractiveness. The reductions in *P. xylostella* numbers are of particular significance to Brassica producers as this insect has the proven ability to become resistant to every known insecticide, therefore any non-chemical control method could result in substantial reductions in insecticide use and insecticide resistance. However, *P. rapae* was not affected by the rye cover crop presumably due to superior host location ability and egg spreading behaviour. These results were supported by data from a semi-commercial trial.

In contrast to the previous years results, rye cover crop was shown to have significant effects on broccoli growth, reducing the number of leaves, plant biomass and yield as well as again delaying harvest by approximately one week. However, the rye cover crop improved the quality parameters, reduced the severity of hollow stem, eliminated excessive branching and removed the need for mechanical weeding.

An economic analysis based on the experimental outcomes of this thesis indicated that using the rye cover crop in a broccoli production system reduced the total variable costs by $323/ha (6.7%) but also reduced the gross margin by $151/ha (5.9%) when compared to conventional practice. However, only a 2% increase in yield, or a 7% price premium due to the reduced chemical use, would be required to eliminate this deficit.

The study also showed that mechanical challenges stemming from increasing plant species diversity in existing vegetable cropping systems, could be readily overcome through the modification of existing, commercially available farm machinery/equipment.

In summary, introducing plant species diversity into the conventional vegetable cropping system, in the form of a cover crop, showed considerable benefits to broccoli production in terms of reduced insect pest pressure and quality improvements. Strip cropping as a diversification strategy did not result in increased yields or quality and had no significant effect on insect behaviour in the crops studied. Furthermore, this approach would be more difficult to implement commercially than the rye cover crop due to increased management complexity and incompatibility of chemical weed management strategies. Therefore future research efforts should focus on increasing plant species diversity in the vertical plane (above and below) using cover crops, rather than the horizontal plane (side by side) using strip cropping.

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Glossary of Terms

Strip crops – growing two or more crops in tractor width repetitions.

Cover crops – plants grown for ground cover that are killed prior to planting a commercial crop.

Bare soil – soil without ground cover that has been cultivated to a fine tilth.

Oviposition – the process of an insect depositing an egg.

DAT – number of days after a seedling has been transplanted.

Host location – the process an insect undertakes when attempting to find a suitable host plant.

Cosmopolitan insect – an insect that is found wherever its host plant is cultivated.

Instar – a post embryonic insect growth stage between moults.

Alatae – winged female aphids.

Apteratae – wingless female aphids.

Degenerate – having lost highly developed functions, characteristics or structures through evolution.

Gravid – carrying developing young or eggs.

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Chapter 1 Introduction

This thesis began as a personal concern rather than an immediate industry based problem. This concern started to develop as I grew up on my parent's mixed crop and livestock property, on the northwest coast of Tasmania, and continued to develop as I worked as a contract vegetable grower before attending University and completing my degree in Agricultural Science. During these years, vegetable production systems increased in scale, and in the process become more reliant on agrochemicals to control competing organisms. My developing apprehension was that agriculture was becoming too reliant on chemicals inputs, which had the potential to increase problems in the future and was perhaps not the best way forward for the industry. These points initiated the question, "Are there any feasible alternatives?" This question forms the starting point of this thesis. However, before beginning to explore this question, the reasons for the current trends in vegetable production systems need to be understood.

1.1 Current trends in modern vegetable production systems

Since the geographical expansion of agriculture slowed markedly in the 1950's, crop yield increases accelerated, more than keeping pace with population growth. This resulted in a worldwide oversupply of food (Swaminathan 2004). Globalisation in agriculture and the continued breakdown of trade barriers enlarged the market available to Australian farmers but also increased the number of competitors (Barr 2004). Both oversupply and globalisation have meant continued downward pressure on agricultural product prices and declining margins between real farm receipts and real farm costs (Laurence 2000). This has led to worldwide structural changes in agriculture over the last four decades characterised by increased mechanisation, intensification of production, increasing use of external inputs and the separation of livestock and crop production (Knickel 1990).

On average, over the last 15 years, agricultural output in the Organisation for Economic Co-operation and Development (OECD) countries has increased by 15%, on 1% less land with 8% fewer workers. At the same time the inflation adjusted price of food has fallen by approximately 1% per annum (Legg and Viatte 2001). To remain globally competitive

Australian farms have become larger, more capital intensive and fewer in number (Garnaut and Lim-Applegate 1998). There has also been increasing pressure to specialise rather than diversify (Stuthman 2002) as specialisation brings economies of scale though greater mechanisation, the use of hybrid germplasm and the focusing of knowledge, research and marketing (Vandermeer *et al.* 1998). Only 50 years ago vegetable producers in Australia were small, diverse, labour intensive operations on the urban fringe with few chemicals and fertilisers available. In comparison, modern vegetable producers are highly productive, large scale, increasingly specialised operations dependent on irrigation, fertiliser, agrochemicals, transport and marketing systems and found in regions where the climate, soil and water supplies are most suited to the production of specific crops (Stirzaker 1999). Access to markets and the relative prices of outputs and inputs strongly influence the selection of crop types, crop sequences and crop management (Boiffin *et al.* 2001).

While these farming systems are extremely productive and provide low-cost food (Altieri 1998; Stirzaker 1999) they also bring a variety of economic, environmental and social problems (Altieri 1998). A focus on maximising production in the short-term without consideration of the consequences on other essential components of the agro-ecosystem has led to natural resource degradation in Australia (Williams and Gascoigne 2003). The annual cost of this resource degradation, which includes salinity, acid soils, soil structural decline, erosion, irrigation salinity, reduced water quality and invasive weed control, has been estimated to be in excess of $A 3.5 billion (Standing Committee on Environment Recreation and Arts 2001).

At the individual farm level there has also been a subsumption of the decision making process by corporations as part of the contracting process (Tonts and Black 2002). For example, in Tasmania, vegetable processing companies make most of the decisions in relation to the selection of varieties, planting and harvesting dates, irrigation schedules, chemical applications and fertiliser requirements, and usually award annual contracts less than a year in advance (Miller 1995). This compounds the imbalance between economic and environmental imperatives, as there is little opportunity for forward planning and attempts to achieve sustainability are afforded low priority (Miller 1995).

There are very few native Australian plants that are grown as crops in any capacity. Instead crops are drawn from a diverse range of geographic locations, from South America to Europe. As a result the remnant ecosystems dispersed throughout the cropping locations have a long evolutionary history distinct from that of the introduced crops (Hill 1993). Therefore most pests, predators and diseases are also exotic in their origin. The insect pest situation is further complicated as many species have the ability to migrate in large numbers on favourable winds, at times inundating biological control mechanisms (Hill 1993).

These factors, combined with modern agriculture's reduced tolerance of weeds, pests and diseases (Vandermeer *et al.* 1998), means maintaining the productivity of soils and sustaining the rural environment in the face of declining farm profitability, is seen as the single most important issue in many agricultural industries today (Laurence 2000). Furthermore, Trewavas (1999) suggests that along with abundant (and cheap) food and greater life expectancies, has come a demand from consumers for a risk free world. Since modern farming practices have been fairly or unfairly associated with chemicals and health risks, there is an increasing demand for 'clean green' chemical free food. There have also been calls for greater use of 'sustainable' production methods in Australia due to continual scrutiny of agricultural production methods by an increasingly urbanised population coupled with an agricultural lobby with waning political power (Barr 2004). These demands are increasingly being reflected in the requirements of retailers, particularly the economically powerful supermarkets in Europe (Gunningham and Sinclair 2002) and Australia.

In summary, the current trends in Australian vegetable production are that increased global supply and competition has resulted in increased farm efficiency, management simplicity, greater reliance on inputs (including agrochemicals) and increased scrutiny by a largely urban public who desire "sustainably" produced goods. Therefore, research into vegetable cropping systems that maintain efficiency and productivity, but at the same time reduce the level of chemical inputs, could result in more marketable products and be an alternative to a continued reliance on chemical solutions. Researching strategies to reduce chemical dependence in vegetable production also aligns well with current Australian agricultural policy statements, for example Tasmania's state government policy and promotion of Tasmanian agricultural industries as being "clean and green", with low chemical usage, and a moratorium on any use of gene technology in the production of food (Anon 2003b).

1.2 Steps in this research

The search for a feasible alternative to the current trend of increased chemical dependence in vegetable production systems, initially involved discussing the problems of chemical dependence and the benefits and disadvantages of farming systems with reduced chemicals requirements. This led to the initial choice of research direction that was further developed via a review of relevant literature (Chapter 2). This in turn generated specific research questions, with preliminary field investigations commencing in the summer of 2003/2004 with the strip cropping of potatoes (*Solanum tuberosum*), broccoli (*Brassica oleracea* var. *italica*) and onions (*Allium cepa*) (Chapter 3). Initially this project was conceived as a broad look at problems and potential solutions to chemical dependence in each of these three vegetable crops. However, the results from the initial trial demonstrated that the most interesting trends were occurring in broccoli, which is a good example of an intensively produced vegetable with the associated problems of insect pest pressure, insecticide resistance, weed pressure and rapid growth. Therefore the majority of the work in the following two years concentrated on broccoli as a key part of an intensive system. The major focus of this thesis relates to the impact of cover and strip cropping on insect populations in broccoli (Chapter 4). Agronomic and economic impacts are discussed in Chapter 5 and machinery design aspects in Chapter 6. The research detailed in this thesis covers a wide range of subject matter within the field of agricultural science including agronomy, entomology and agricultural engineering. The final chapter, Chapter 7, summarises these different aspects and discusses future research directions.